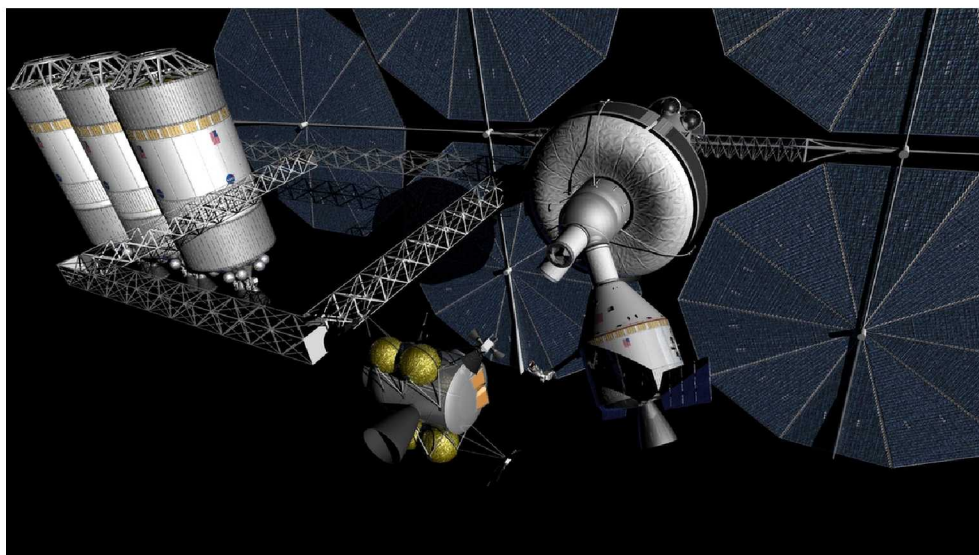
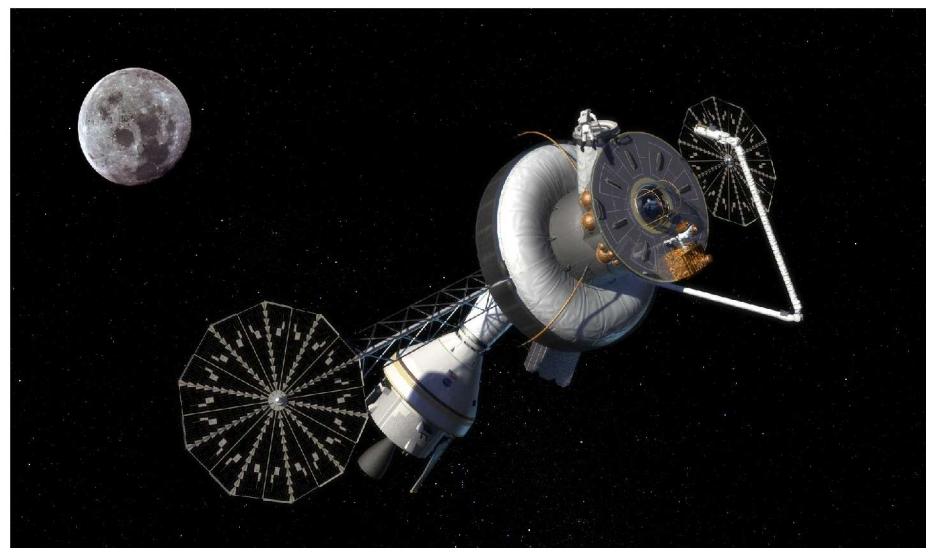


Human Exploration Beyond LEO by the End of the Decade: Designs for Long-Duration “Gateway” Habitats

[REFERENCE: FISO “Gateway” Concepts 2010]



Heavy-Lift “Gateway” Design: libration-point depot maintenance concept to enable lunar surface support
(Courtesy: FISO Working Group and JF&A)



Dual-EELV “Gateway” Design: Earth-Moon L1,2 “job site” concept to demonstrate long-duration human capabilities and “telepresence” operation of lunar surface robots.

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FISO Telecon Colloquium: December 15, 2010

See <http://www.futureinspaceoperations.com>

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Designs for a Long-Duration Habitat Beyond LEO by the End of the Decade

SUMMARY

For the past few years, designs have been developed that are intended to demonstrate that a long-duration habitation system beyond LEO is plausible within several years, should that be NASA priority.

Here we summarize a pair of designs *with the overriding goal of development and operation beyond LEO before the end of the decade* that also build upon experiments and lessons learned from ISS.

Both derive from the detailed 2001 DPT JSC “Gateway,” which was sized to fit an assumed future “Exploration-class” Delta IV H variant with one subsequent Shuttle and one smaller EELV outfitting flights.

Both concepts here have the goal of an expandable long-duration habitat at Earth-Moon L_1 and/or L_2 . Both options require subsequent launches for the astronauts.

If a heavy-lift launch vehicle is available this decade, an expandable 30.5 mt habitat and departure-stage propulsion system may be launched to E-M $L_{1,2}$ in a single launch and will offer 575 m³ (roughly half the habitable volume of ISS)

If existing (or near-future) EELVs are the available launch vehicles this decade, a 16 mt, 170 m³ design that uses a pair of launches of Delta IV H and LEO rendezvous/fuel transfer to reach E-M $L_{1,2}$.

Goals for Future Long-Duration Human Operations Beyond LEO

Priorities for future long-duration human operations to achieve science and human space flight priorities must

Build upon experience gained via extended ISS operations

Our “Gateways” are designed to incorporate robust, more compact versions of systems developed on ISS, as well as designs for lunar surface habitats

Achieve priority human exploration goals

A libration point operations site may be used as a lunar surface sortie staging and support site, for example, for operations of lunar surface robots, depot maintenance facility, and the first “stepping stone” beyond LEO toward more ambitious missions

Achieve priority science goals

Combined astronaut/robotic assembly and upgrade of future very large optical systems may be required to achieve the highest Agency science priorities

Combine collaborative strengths of government, industry, and academia

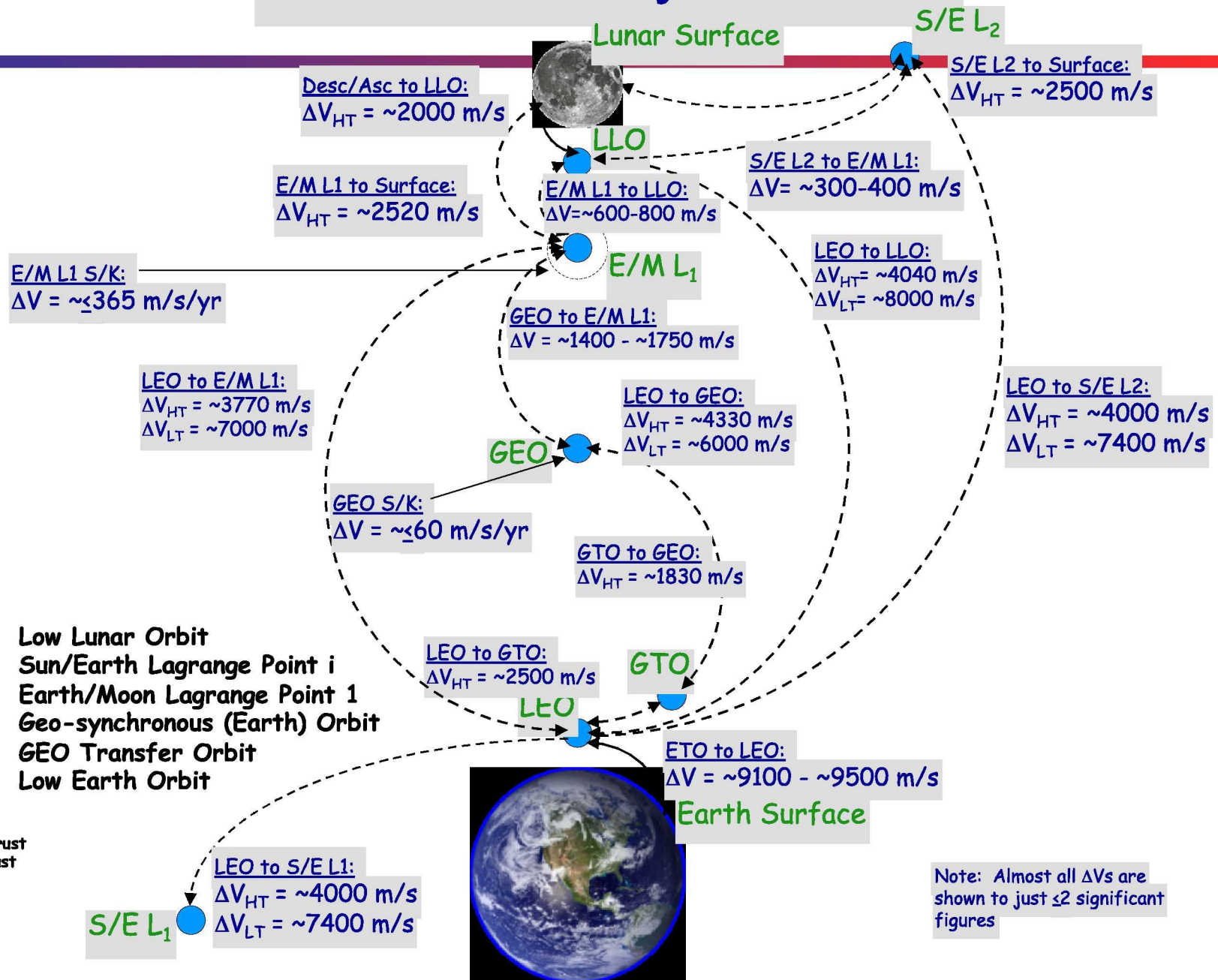
Significant technology and design capabilities exist throughout academia, industry, and the government to justify collaborative work from the start

Candidate Significant Near-Term Capabilities for Human Operations Beyond LEO

Our preliminary design for a “Gateway” at the Earth-Moon $L_{1,2}$ “stepping stone” responds to the current political/budgetary opportunity for human space flight by the end of the decade and may permit

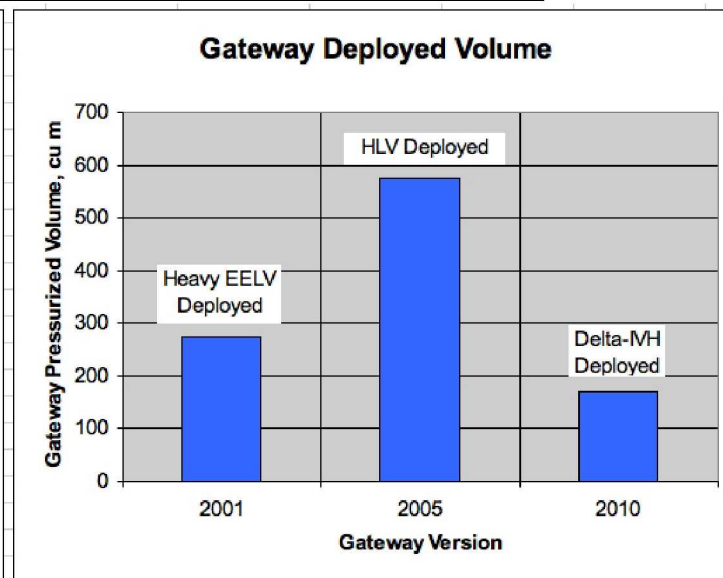
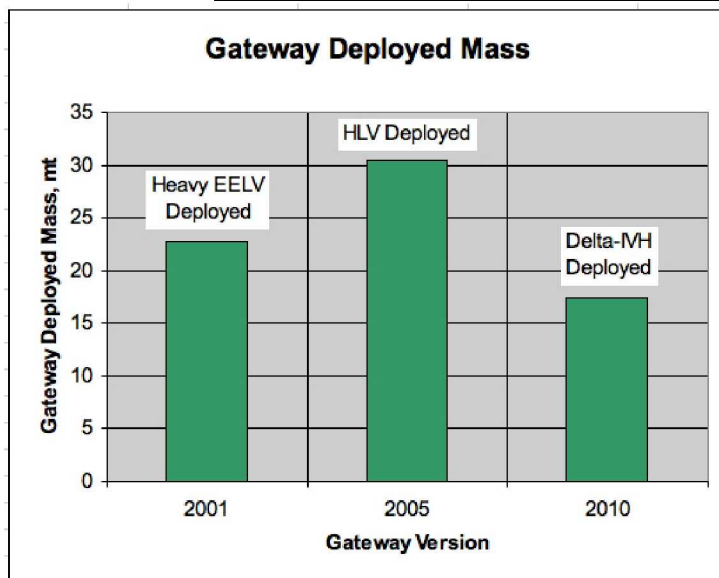
- A major demonstration with, for example, next-generation systems developed via ISS experience and operating beyond LEO for the first time
 - exercises, in a cis-lunar environment, systems developed on ISS
- In addition to being the (dynamically) easiest major candidate operations site to reach beyond LEO, a “Gateway” at E-M $L_{1,2}$ by the end of the decade may enable
 - Early lunar exploration ‘beachhead’: e.g., line-of-sight, small time-delay operation of surface robots across a full hemisphere (e.g., Lester & Thronson 2011, *Space Policy*, in press)
 - Demo of complex construction and upgrade, including site preparation for subsequent major assembly operations (e.g., very large optics) & maintenance of lunar-support depots

Earth-Moon System ΔV s



Gateway Comparisons

"Gateway"	DPT JSC 2001	FISO 2005	FISO ULA 2010
Launch Vehicles	Heavy EELV + STS	HLV + D-IVH	D-IVH
Mass (mt)	22.8	30.5	17.5
Pressurized Volume (m ³)	275	575	170
Crew Size	4	4	3
Deploy Flights	2 x 35 mt "Exploration Class" D-IV Heavy	1 x 95 mt HLV	2 x 28 mt D-IVH
Outfitting Flights	1 x STS	None	Combined w/crew flight
Crew/Logistics Flight	1 x Space-based CTV	2 x D-IVH	2 x D-IVH
Upper stage	SEP	Chemical, SEP	Chemical



Heavy-Lift Vehicle Option

Design Approach

Point of Departure: 2001 DPT JSC “Gateway” (*EX15-001-01*), with a mass of 22,827 kg, was sized to fit an assumed future “Exploration-class” Delta IV H variant with one subsequent Shuttle and one smaller EELV outfitting flights.

The heavy-lift vehicle adopted by our 2006 follow-on study to launch a larger “Gateway,” offered 95 mt to LEO and a 6.5 m x 25 m fairing and availability within a decade.

Proposed to NASA HQ ESMD to achieve additional goals by adapting hardware developed for Constellation program: that is, an *Apollo Applications Program* for the 21st Century.

Entire “Gateway” and departure/orbit insertion stage launched as a single unit

Improved radiation protection offered by HLV capabilities

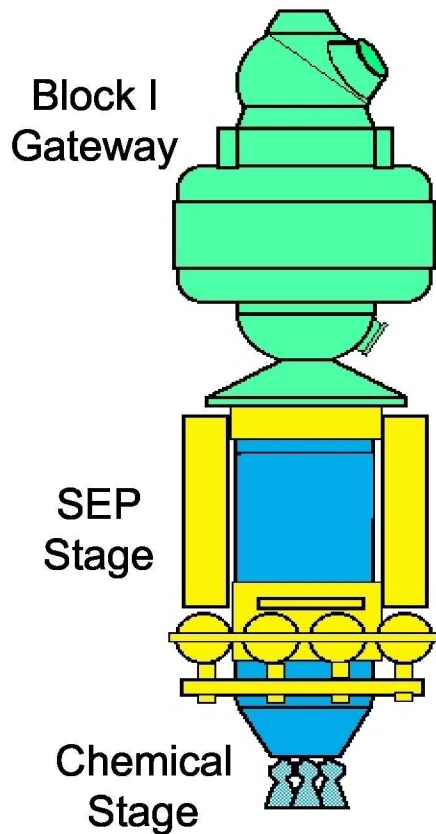
Options were explored for different Earth departure and orbit insertion stages.

Reusability was assessed: SEP and RL-10 chemical stage not reused (unless Xenon propellant provided at $L_{1,2}$ to return stage to LEO)

Crew vehicle launched separately

Heavy-Lift Vehicle Option: Design Summary

Undeployed Stack



Design lifetime: 15 years (4 crew @ up to 4 missions/yr)

Total volume: 575 m³ (~ 45% of ISS complete)

Overall mass: 95 mt

Gateway: 30.5 mt SEP stage: 17.0 mt LOX/LCH4 stage: 47.5 mt

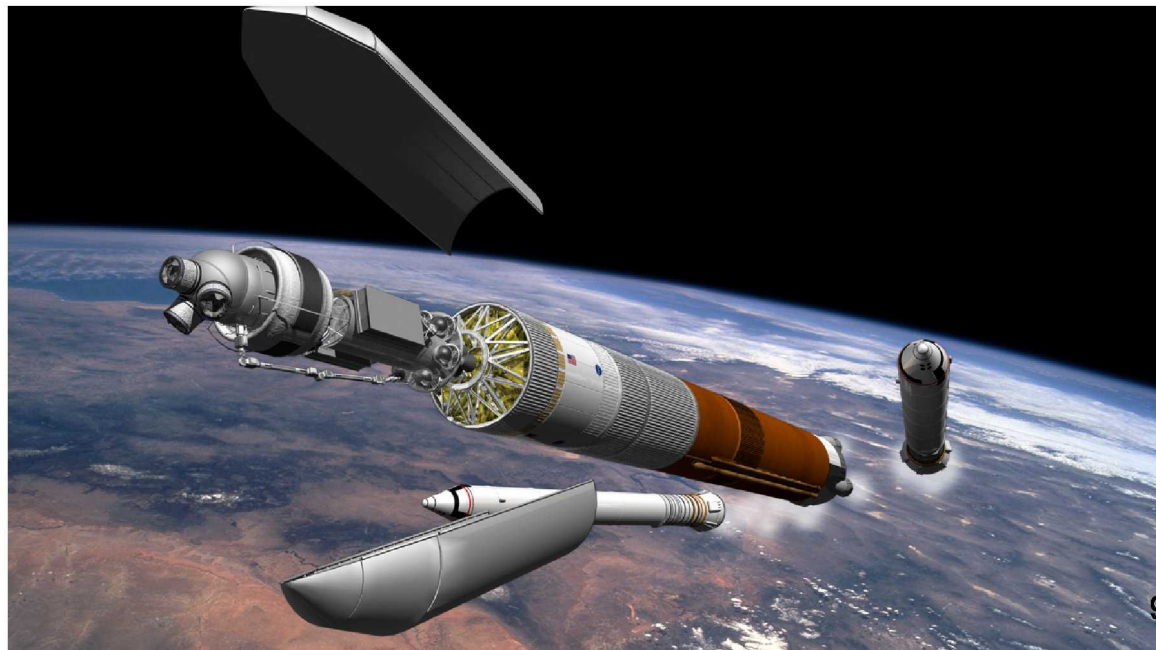
Overall length: 19.8 m Overall diameter (max): 5.8 m

Main chemical propulsion: 3 RL-10 engines (@ 25 klbf; LOX/methane: Isp = 370 s

Main SEP propulsion: 6 Hall Effect 50 kW engines (Cryo Xenon; 3650 m² PV arrays)

Additional radiation shielding and "storm shelter" in central core

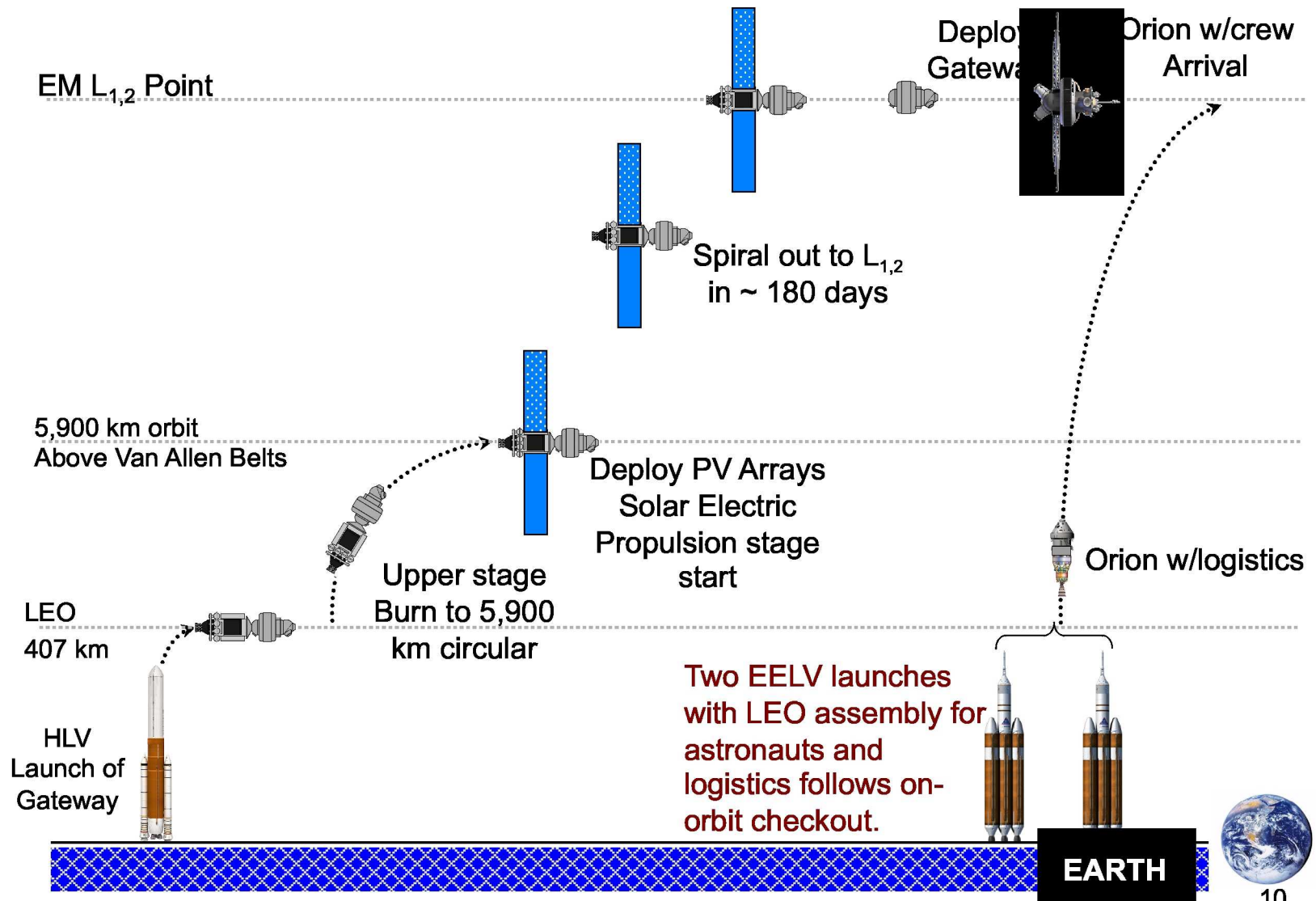
*HLV launch to LEO of
"Gateway" stack.*



Earth-Moon $L_{1,2}$ Mission Outline

One-Launch HLV "Gateway" Option 2

[Other Options Under Consideration]



Dual-EELV Option:

Design Approach

Point of departure: the 2001 E-M L1 DPT JSC “Gateway” (*EX15-01-001*) was 22,827 kg and appeared capable of achieving priority goals for libration-point operations.

Our goal was to get below 16,000 kg, which could be accommodated by a pair of launches by near-future Delta IV Hs.

Compared to the 2001 DPT JSC design (all masses include 30% margin):

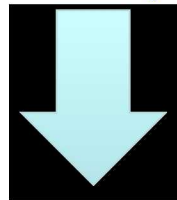
- Maintains ~15-year lifetime with capability for 4 astronaut missions/yr
- Maintains significant EVA, robotic arm capability
- Reduced inflatable shell outer diameter
 - Was 9.4 m, now is 7.6 m
- Reduced core diameter & length
 - Was 4 m dia and 6.5 m long
 - Now is 3.5m dia and 6.5 m long
- Reduced crew size from 4 to 3
- Number of docking ports reduced from 3 to 2; 3rd installed later
 - Multiple modules may be docked together (under consideration)
- Removed 1,500 kg of outfitting: to be brought up on later supply mission
 - Exercise and science equipment, tools, some spares, etc.

Mass-Change Deltas from 2001 DPT JSC “Gateway”

Gateway Elements Changed	2001 Version, kg	2010 Version, kg	Change, kg	Rationale
Avionics	251	116	-135	Based on 2009 lunar systems habitat study
ECLSS	2,852	1,664	-1,188	Reduce crew from 4 to 3; lunar systems habitat study subsystems
Thermal Control System	665	354	-311	Lunar systems habitat study
Human Factors	2,508	1,402	-1,106	Reduce crew from 4 to 3; Simpler galley & crew quarters, exercise facility + science equipment and maintenance tools brought up on logistics flight
EVA Tools	132	0	-132	EVA tools brought up on logistics flight
Inflatable shell	1,618	1,001	-617	Reduce crew size - reduce diameter and height
Core structure	1,356	1,110	-246	Core diameter reduced from 4-m to 3.5-m to reduce overall diameter to fit Delta IV fairing
Docking adapters	1,997	1,331	-666	1 of 3 adapters brought up on logistics flight
EVA work platform & struts	364	289	-75	Reduce diameter from 6-m to 5-m
Secondary structures	1,471	277	-1,194	25% of core structure only
Robonaut & workstation	136	0	-136	Brought up on logistics flight
Interstage Adapter	200	374	174	Revised upward for Delta-IVH
Unchanged Subsystems	3,036	3,036	0	Unchanged subsystems
Subtotal inert mass	16,586	10,955	5,631	Sum of all inert mass changes
30% margin on inert mass	4,976	3,287	1,689	Based on reduced inert mass
Propellant RCS	1,268	828	440	Based on reduced total mass
Total Gateway Changes			7,760	Total reduction of Gateway mass that carries 30% margin

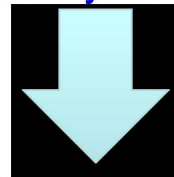
Dual-EELV Option: Existing and Near-Term Upgrade of Capability

Launch vehicle adopted
for this study.



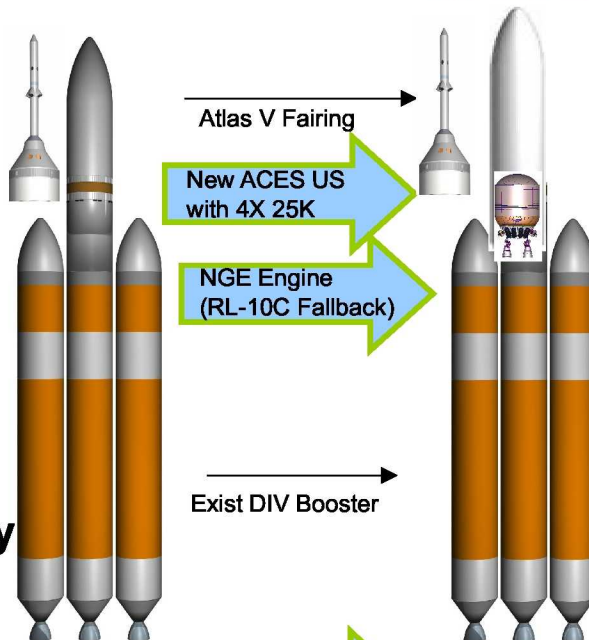
28 mt LEO

Launch vehicle adopted
for next study: increased
“Gateway” volume



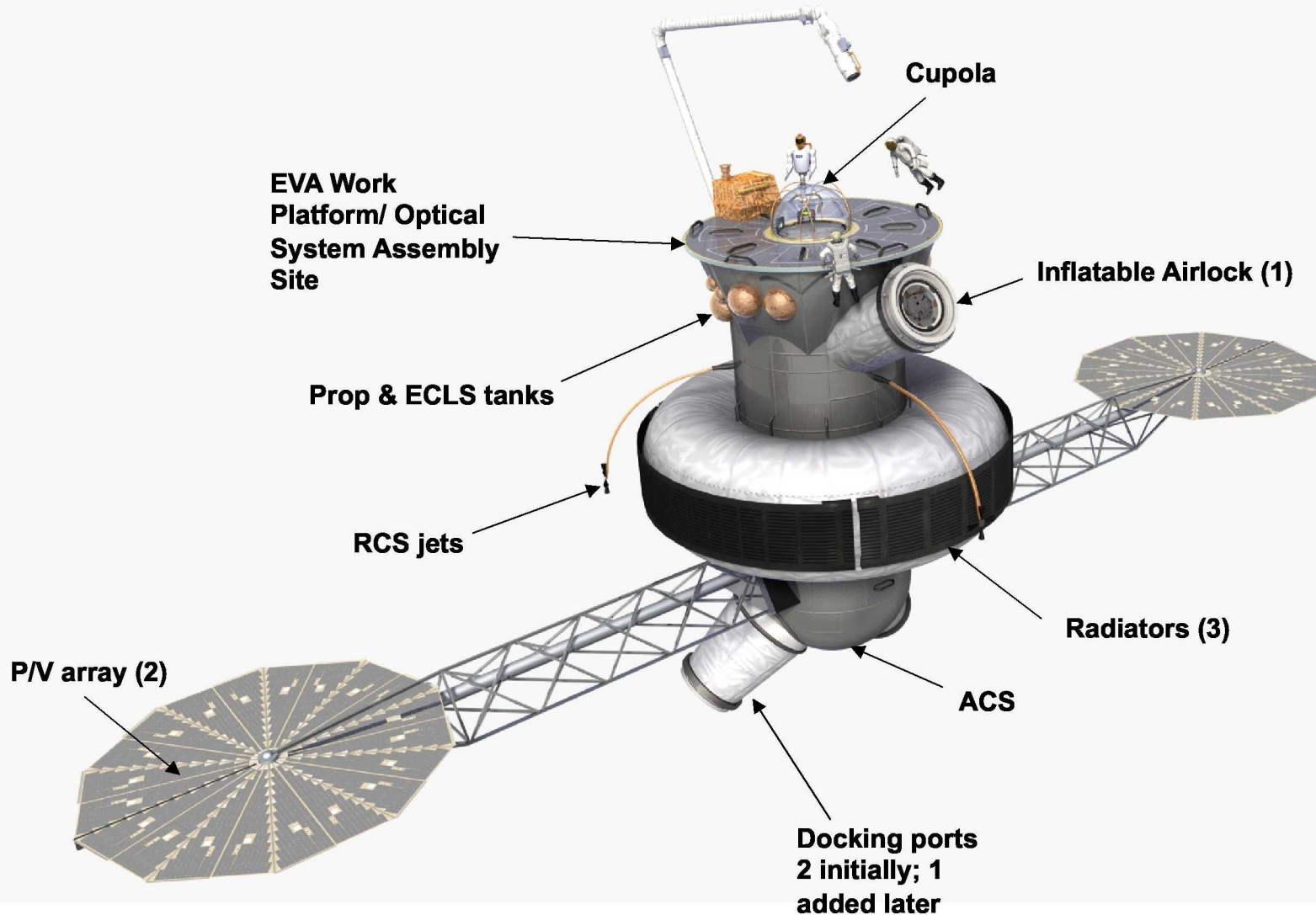
35 mt LEO

Near-Future Delta IV Heavy
(RS68A; 5 m DCSS Upper
Stage)



**Delta IV Heavy
with Phase 1 Upgrade**
(ACES Upper Stage)

Engineering Visualization: Near-Term Dual-EELV “Gateway”

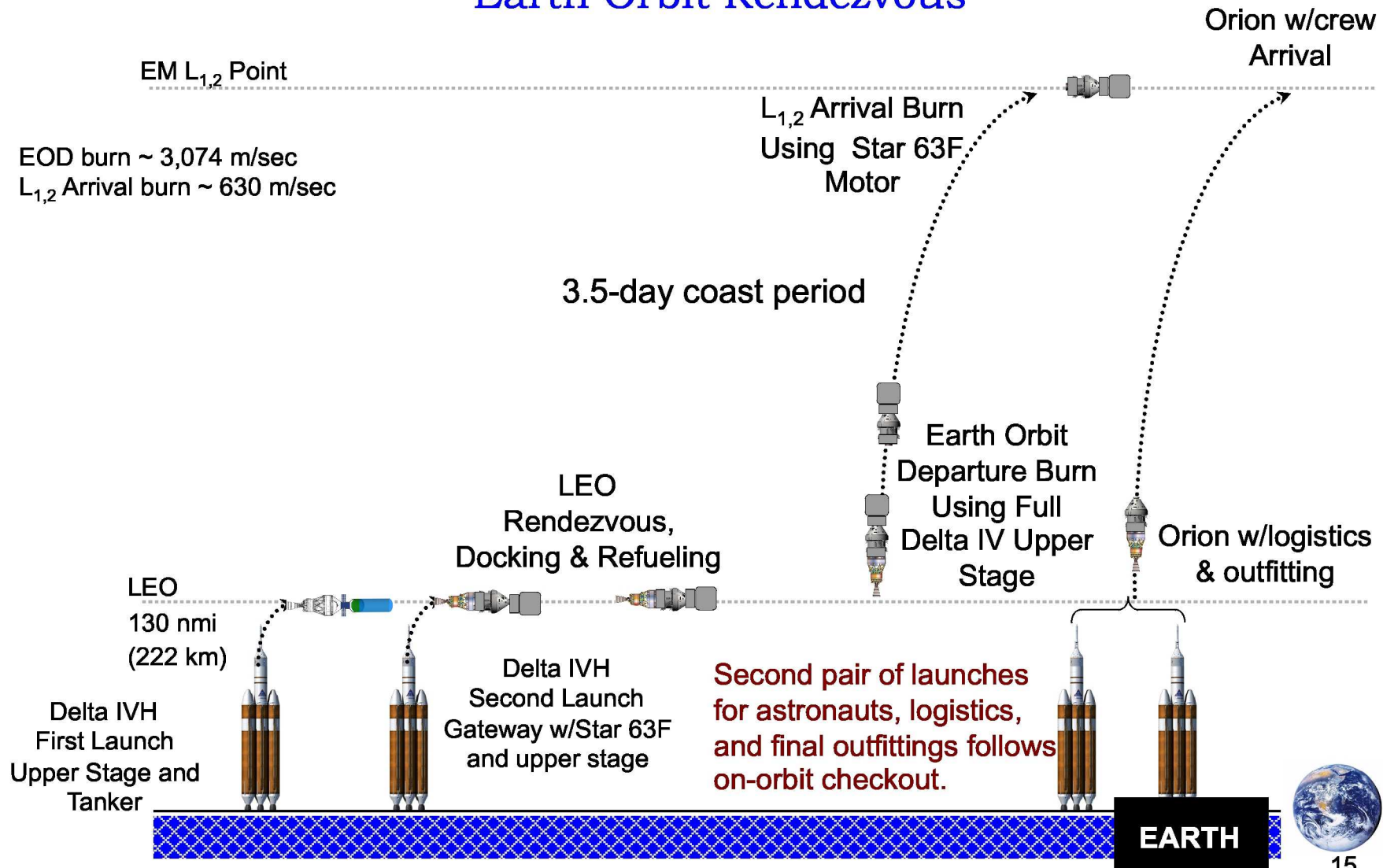


Earth-Moon $L_{1,2}$ Mission Outline

Dual-EELV “Gateway” Option 1

[Other Options Under Consideration]

Earth Orbit Rendezvous



Dual-EELV “Gateway” Element Summary

- Design Lifetime: 15 yrs (3 crew @ up to 4 missions/yr)
- Launch Vehicle: 2 x Delta IV H (w/RS68A)
- Earth departure stage: DCSS (Delta IVH upper stage)
- E-M L1 injection stage: ATK Star 63F (2.6 mt)
- “Gateway” Mass:
 - Launch: 16 mt
 - Outfitting: 1.5 mt
 - Post-outfitting: 17.5 mt
 - Resupply mass/volume:
 - 3 months: 900 kg / 3.8 m³
 - 6 months: 1600 kg / 7.5 m³
- Total Volume:
 - Launch: TBD m³
 - Operational: 170 m³
- Support Missions:
 - Outfitting at E-M- L1: One mission/architecture
 - HF&H consumables: Two missions/year
 - ECLSS/Prop: One mission/two years
- Estimate Element Cost: TBD
 - [Cost estimate for roughly similar design is in DPT JSC report EX15-01-001]
- Astronaut mission to “Gateway” requires additional two Delta IV H launches

Propellant Tanker Summary

- **Delta IV H performance = 28 mt**

(400 km circ, 27°)

- Drop tank = 1.0 mt
- Mission Mod = 1.0 mt
- Transfer loss = 0.3 mt
(chill and residuals)
- 30 day boil-off = 0.6 mt
- Margin = 0.5 mt

- **LEO propellant = 24.6 mt**
(available for EDS burn)

- **Drop Tank Boil-off**

- Centaur flown = 2%/day
- Min mods = 1%/day
- Centaur + = 0.3%/day
- Drop tank < 0.1%/day

Tank + TPS = 0.7 mt

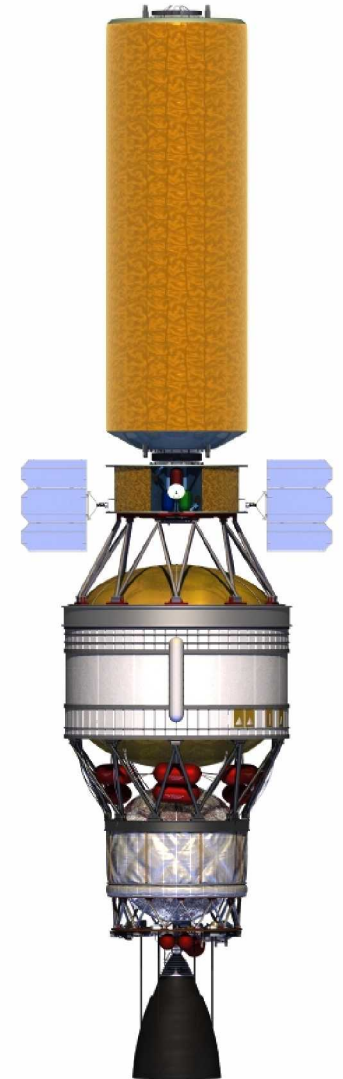
40 layer MLI
(min penetrations)

Enhanced IB spacer
Vapor cool IB

Low conductivity struts

Mission Module = 0.9 mt

DCSS 5 m = 3.5 mt



Dual-EELV Design:

Is There Sufficient Habitable Volume for Long Duration?

[See Backup for Calculation]

Total Pressurized Volume *	163 m ³
Habitable Volume	81.5 m ³

Assumes Net Habitable Vol. = 55% of Total Pressurized Volume

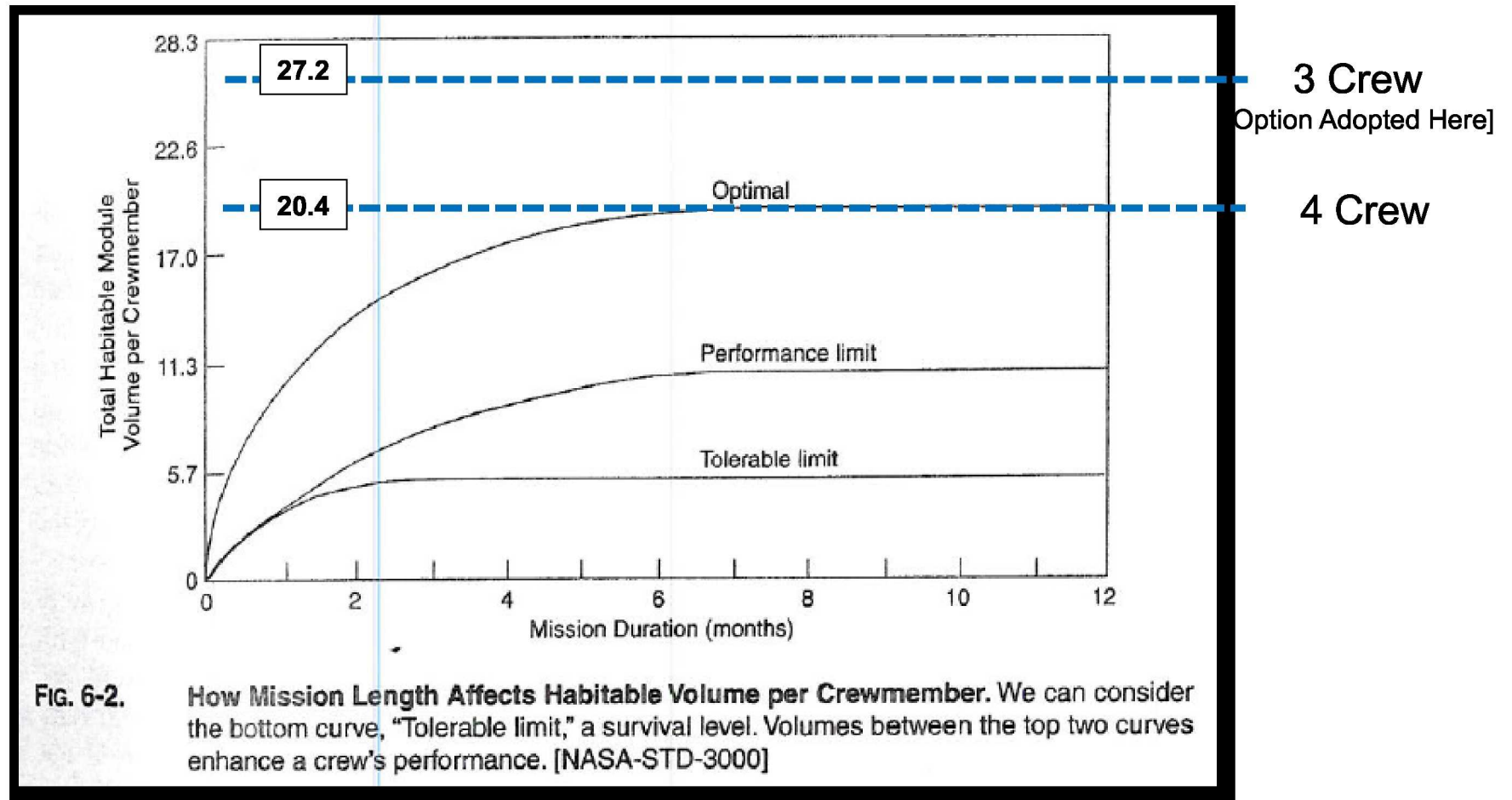
Reference:

Orion = 55% Net Habitable Volume.

Habitable Volume per Crew	
2 Crew	40.8 m ³
3 Crew	27.2 m ³
4 Crew	20.4 m ³

* Does not include estimate for airlock, transfer tunnels, and crew module

Calculated Volume Exceeds Recommended Values for “Optimal” Long-Duration Habitation



Habitable Volume compared to NASA-STD-3000

(Does not include volume estimate for airlock, transfer tunnels, and crew module)

Logistics Estimation (Mass & Volume) as a Function of Number of Crew & Mission Duration

3-4 crew / 2-3 months

934 - 1,200	Total Logistics Mass (kg)
3.98 - 5.11	Total Logistics Volume (m ³)

		DURATION (days)							
		10	30	60	90	120	180	500	900
# of CREW	2	150.23	281.50	478.39	611.49	778.38	1112.18	2892.40	5117.68
		0.64	1.20	2.04	2.60	3.31	4.73	12.31	21.78
	4	278.46	540.99	934.78	1200.98	1534.77	2202.35	5762.80	10213.36
		1.18	2.30	3.98	5.11	6.53	9.37	24.52	43.46
	6	406.70	800.49	1391.18	1790.46	2291.15	3292.53	8633.20	15309.04
		1.73	3.41	5.92	7.62	9.75	14.01	36.74	65.14
	8	534.93	1059.98	1847.57	2379.95	3047.54	4382.70	11503.60	20404.72
		2.28	4.51	7.86	10.13	12.97	18.65	48.95	86.83
	10	663.16	1319.48	2303.96	2969.44	3803.92	5472.88	14374.00	25500.40
		2.82	5.61	9.80	12.64	16.19	23.29	61.17	108.51

Candidate Capability Investments

We have proposed to NASA to develop a detailed technology capability investment strategy to enable long-duration habitation systems deployed beyond LEO before the end of the decade.

It is likely that technologies necessary for our concept will be attractive to other human space flight goals. Moreover, significant progress is being made toward these priorities.

As part of this preliminary work, we consider enabling capabilities for the dual-EELV option to include

- On-orbit re-fueling (i.e., Earth departure stage in LEO)
- Improved designs, structures, and materials for expandable facilities
- Improved long-duration systems/sub-systems developed as a testbed in coordination with ISS
- Improved EVA and robotic systems: suits, environment control, airlock, tools, etc.
- Enhanced telepresence systems to enable remote operation of lunar surface robots.

REFERENCES

Selected works on future in-space operations concepts: <http://www.futureinspaceoperations.com>

Archived documents from the Decade Planning Team (DPT): <http://history.nasa.gov/DPT/DPT.htm>

See: Decade Planning Team JSC 2001 "Gateway" architecture (EX15-001-01)

Selected reports on libration points as operations sites (chronological order):

*Site Selection and Deployment Scenarios for Servicing of Deep-Space
Observatories* IEEE 0-7803-7231-X (2001)

Conceptual Design of a Lunar L1 Gateway Outpost IAC-02-IAA.13.2.04 (2002)

*Utilization of Libration Points for Human Exploration in the Sun-Earth-Moon
System and Beyond* IAC-03-IAA.13.2.03 (2003)

Strategies for Servicing the Single Aperture Far IR (SAFIR) Telescope
SPIE 5899-21 (2005)

Destinations for Exploration: More than Just Rocks? Space Review, July 16, 2007

*Using NASA's Constellation Architecture to Achieve Major Science Goals
in Free Space* IAC-08-A5.3.6 (2008)

*The "Flexible Path" from The Review of US Human Space Flight Plans (aka, The
Augustine Committee)* <http://www.nasa.gov/offices/hsf/home/index.html>

First Stop for Flexible Path? Space Review, November 30, 2009

*Review of US Concepts for Post-ISS Space Habitation Facilities and
Future Operations* AIAA Space 2010 #818583 (2010)

Human Space Exploration and Human Space Flight: Latency and Cognitive Scale of the Universe,
Space Policy, in press (2011)